

# PERFORMANCE OF KENAF FIBRE REINFORCED CONCRETE UNDER STATIC AND DYNAMIC LOADINGS

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PERFORMANCE OF KENAF FIBRE REINFORCED CONCRETE UNDER  
STATIC AND DYNAMIC LOADINGS

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To my beloved parents father and mother

Thanks for your support

I am very proud to have all of you

~~~~~ Love you all ~~~~

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## ABSTRACT

Concrete is considered as a brittle material, its enrichment with distributed short kenaf fibres is believed to increase the toughness of matrices. This is achieved by prohibiting the concrete from being cracked and propagated. Kenaf is a natural fibre has typically some benefits such as being renewable, eco-friendly, biodegradable and locally accessible as compared to other types of fibres used for concrete reinforcement. This study was conducted experimentally to investigate the characteristics of kenaf fibre reinforced concrete (KFRC) materials and to determine the performance of kenaf fibre reinforced concrete beams under static and dynamic loadings. The basic concrete materials used in the study are 10 mm aggregate, ordinary portland cement and clean water. Mixing procedures were evaluated to produce KFRC materials with different chopped fibre lengths (10 mm, 15 mm, 20 mm, 25 mm and 30 mm) and fibre volume fractions (0.5%, 1%, 1.5% and 2%). At the preliminary stage, the alkaline treatment test was carried out on the kenaf fibres. Then, the raw materials and concrete properties were investigated by a series of physical and mechanical property tests on fresh and hardened concrete to identify the optimum characteristics of fibre length and content to be used in the concrete mixture. The study also investigated the structural behaviour of KFRC beams, in which the samples were undertaken by monotonic bending load and repeated bending load tests under four points loading system until failure. The load-deformation behaviour of the beams was observed and monitored during testing. Results from the study of alkaline treatment on kenaf fibres found that the best condition was 5% NaOH in three hour emerging time. The study also found that the optimum length of kenaf fibres was 20 mm and the optimum volume fraction yields the value of 1%. From the KFRC beam tests, it was found that the KFRC beams exhibited better performance as compared to normal concrete beams. The best static and dynamic behaviour was observed for the beam using KFRC in tension zone and plain concrete in compression zone, with the ultimate bending load of 5.9% higher than normal concrete beam after the flexural test and 15.6% higher than normal concrete beam after the repeated load test. By observation, the number of crack formation in tension zone increased by 40% and crack spacing was less by 15% as compared to normal concrete beams. The total energy absorption from the load-deflection behaviour of KFRC beams until ultimate failure was 77% higher than normal concrete beams. The relationships between KFRC material and structural performance against fibre lengths and volume fractions have been developed based on the non-linear numerical models and proposed for the analysis and design of KFRC. Conclusively, KFRC material and structure exhibit appreciable tensile, flexural, and impact strength under static and dynamic loadings compared to normal concrete.

## ABSTRAK

Konkrit ialah bahan rapuh, pengayaan dengan gentian kenaf pendek secara agihan seragam dipercayai mampu meningkatkan pengukuhan matriks. Ini dicapai dengan mengekang konkrit daripada retak serta berkembang. Kenaf adalah gentian asli mempunyai beberapa kelebihan antaranya sebagai sumber yang boleh diperbaharui, mesra alam dan mudah diperoleh berbanding lain-lain jenis gentian yang digunakan sebagai tetulang konkrit. Kajian ini dijalankan secara eksperimen untuk menyelidik ciri-ciri konkrit bergentian kenaf (KFRC) dan menentukan prestasi rasuk konkrit bergentian kenaf di bawah pembebanan statik dan dinamik. Bahan-bahan asas konkrit yang digunakan dalam kajian ini ialah 10 mm agregat, simen portland biasa dan air bersih. Prosedur pencampuran telah dinilai untuk menghasilkan konkrit bergentian kenaf dengan panjang gentian (10 mm, 15 mm, 20 mm, 25 mm, dan 30 mm) dan pelbagai kandungan nisbah isipadu gentian (0.5%, 1%, 1.5%, dan 2%). Di peringkat awal, ujian rawatan alkali dijalankan ke atas gentian kenaf. Selanjutnya, ujian sifat-sifat fizikal dan mekanikal ke atas konkrit basah dan keras telah dijalankan untuk mengenal pasti ciri-ciri panjang dan kandungan gentian optimum yang diperlukan dalam campuran konkrit. Kajian juga dijalankan ke atas kelakuan struktur rasuk KFRC, di mana sampel rasuk diuji dengan beban lenturan monotonik dan beban lenturan berulang di bawah sistem beban empat titik hingga gagal. Kelakuan beban-ubah bentuk rasuk diselidik dan dipantau semasa ujikaji. Keputusan daripada kajian rawatan alkali pada gentian kenaf mendapati bahawa keadaan yang terbaik adalah 5% NaOH dalam tiga jam masa rendaman. Hasil kajian mendapati panjang optimum gentian kenaf ialah 20 mm dan kadar isipadu optimum ialah 1%. Daripada ujian rasuk KFRC, didapati bahawa rasuk KFRC menunjukkan prestasi yang lebih baik berbanding dengan rasuk konkrit normal. Kelakuan statik dan dinamik terbaik bagi rasuk ialah keratan konkrit KFRC dalam zon tegangan dan konkrit biasa dalam zon mampatan, dengan beban lenturan muktamad ialah 5.9% lebih tinggi berbanding rasuk konkrit normal selepas ujian lenturan dan 15.6% lebih tinggi berbanding rasuk konkrit normal selepas ujian beban berulang. Bilangan pembentukan retak di zon tegangan meningkat sebanyak 40% dan jarak retak adalah kurang sebanyak 15% berbanding dengan rasuk konkrit normal. Jumlah penyerapan tenaga dari kelakuan beban-pesongan rasuk KFRC sehingga kegagalan muktamad ialah 77% lebih tinggi berbanding rasuk konkrit normal. Hubungan antara prestasi bahan dan struktur KFRC terhadap panjang dan nisbah isipadu gentian telah diterbitkan berasaskan model berangka tak-linear dan dicadangkan untuk kegunaan analisis dan rekabentuk KFRC. Rumusannya, bahan dan struktur KFRC mempunyai kekuatan yang lebih tinggi dari segi tegangan, lenturan dan hentaman di bawah beban statik dan dinamik berbanding dengan konkrit normal.

## TABLE OF CONTENTS

| CHAPTER      | TITLE                                 | PAGE         |
|--------------|---------------------------------------|--------------|
|              | DECLARATION                           | ii           |
|              | DEDICATION                            | iii          |
|              | ACKNOWLEDGEMENT                       | iv           |
|              | ABSTRACT                              | v            |
|              | ABSTRAK                               | vi           |
|              | TABLE OF CONTENTS                     | vii          |
|              | LIST OF TABLES                        | xii          |
|              | LIST OF FIGURES                       | xvi          |
|              | LIST OF ABBREVIATIONS                 | xxv          |
|              | LIST OF SYMBOLS                       | xxvi         |
| <br><b>1</b> | <br><b>INTRODUCTION</b>               | <br><b>1</b> |
|              | 1.1 Introduction                      | 1            |
|              | 1.2 Background of the Study           | 2            |
|              | 1.3 Statement of the Problem          | 3            |
|              | 1.4 Objective of the Study            | 5            |
|              | 1.5 Scope of the Study                | 5            |
|              | 1.6 Significant of Study              | 6            |
| <br><b>2</b> | <br><b>LITERATURE REVIEW</b>          | <br><b>8</b> |
|              | 2.1 Introduction                      | 8            |
|              | 2.2 Fibres                            | 9            |
|              | 2.3 Fibre Reinforced Concrete         | 10           |
|              | 2.4 Natural Fibres                    | 11           |
|              | 2.5 Kenaf Fibre                       | 16           |
|              | 2.6 Natural Fibre Reinforced Concrete | 21           |
|              | 2.7 Chemical Surface Treatment        | 25           |
|              | 2.7.1 Alkaline Treatment              | 26           |
|              | 2.8 Fibre Volume Ratio and Length     | 29           |

|          |                                                  |           |
|----------|--------------------------------------------------|-----------|
| 2.9      | Moisture Content                                 | 30        |
| 2.10     | Mixture of KFRC                                  | 31        |
| 2.11     | Compressive Properties                           | 31        |
| 2.12     | Tensile Properties                               | 34        |
| 2.13     | Flexural Properties                              | 35        |
| 2.14     | Dynamic Properties of Concrete                   | 36        |
| 2.14.1   | Dynamic Test Approach                            | 37        |
| 2.15     | Summary                                          | 45        |
| <b>3</b> | <b>METHODOLOGY</b>                               | <b>46</b> |
| 3.1      | Introduction                                     | 46        |
| 3.2      | Outline                                          | 46        |
| 3.3      | Materials Used in the Study                      | 49        |
| 3.3.1    | Kenaf Fibre                                      | 50        |
| 3.3.2    | Cement                                           | 51        |
| 3.3.3    | Aggregates                                       | 52        |
| 3.3.4    | Water                                            | 53        |
| 3.3.5    | Distilled Water                                  | 54        |
| 3.3.6    | Sodium Hydroxide (NaOH)                          | 55        |
| 3.3.7    | Supper Plasticizer                               | 55        |
| 3.3.8    | Steel Bars                                       | 56        |
| 3.4      | Experimental Work for Properties of Kenaf Fibre  | 57        |
| 3.4.1    | Pretreatment of Kenaf Fibre                      | 58        |
| 3.4.2    | Untreated Kenaf Fibres                           | 60        |
| 3.4.3    | Chemical Treatment of Kenaf Fibre                | 60        |
| 3.4.4    | Tensile Test on Kenaf Fibre                      | 61        |
| 3.4.5    | Water Absorption Test on Kenaf Fibre             | 63        |
| 3.5      | Optimum Length and Quantity of Kenaf Fibre       | 64        |
| 3.5.1    | Preparing Kenaf Fibre for Concrete Mix           | 65        |
| 3.5.2    | Preparation of Concrete                          | 65        |
| 3.5.2.1  | KFRC Mixture Proportions and<br>Mixing Procedure | 66        |
| 3.5.3    | Preparation of Formwork                          | 68        |
| 3.5.4    | Samples Identification                           | 69        |
| 3.6      | Test on Fresh Concrete                           | 72        |
| 3.6.1    | Slump Test                                       | 72        |
| 3.6.2    | Vebe Time Test                                   | 73        |
| 3.6.3    | Compaction Factor Test                           | 74        |
| 3.7      | Test on Harden Concrete                          | 76        |



|          |                                                      |            |
|----------|------------------------------------------------------|------------|
| 3.7.1    | Water Absorption Test                                | 76         |
| 3.7.2    | Ultrasonic Pulse Velocity (UPV)                      | 76         |
| 3.7.3    | Compressive Strength Test                            | 78         |
| 3.7.4    | Tensile Strength Test                                | 78         |
| 3.7.5    | Quasi-Static Tensile Tests                           | 79         |
| 3.7.6    | Flexural Strength Test for Prism                     | 80         |
| 3.7.7    | Elastic Modulus Strength Test                        | 81         |
| 3.7.8    | Poisson's Ratio                                      | 83         |
| 3.7.9    | Impact Test under Tensile Loading                    | 84         |
| 3.7.10   | Impact Test under Flexural Loading                   | 86         |
| 3.8      | Instrumentation                                      | 87         |
| 3.8.1    | Strain Gauge                                         | 87         |
| 3.8.2    | Demec Gauge                                          | 88         |
| 3.8.3    | The Linear Voltage Displacement Transducer (LVDT)    | 89         |
| 3.8.4    | Hydraulic Jack                                       | 90         |
| 3.8.5    | Load Cell                                            | 90         |
| 3.8.6    | Data Logger                                          | 91         |
| 3.9      | Tests on Kenaf Reinforced Concrete Beams             | 92         |
| 3.9.1    | Preparation of Beam Specimens                        | 93         |
| 3.9.2    | Test Setup for Beam Specimens                        | 97         |
| 3.9.3    | Flexural Four-Point Bending Beam Test                | 98         |
| 3.9.4    | Dynamic Repeated Load Test                           | 99         |
| <b>4</b> | <b>RESULTS FROM EXPERIMENTAL STUDY</b>               | <b>101</b> |
| 4.1      | Introduction                                         | 101        |
| 4.2      | Result of Alkali Treatment for Fibre Surface         | 101        |
| 4.3      | Water Absorption Properties for Kenaf Fibre          | 103        |
| 4.4      | Effect of Treatment on Weight of Kenaf Fibre         | 103        |
| 4.5      | Result of Slump Test of Fresh Concrete               | 105        |
| 4.6      | Result of Vebe Time Test of Fresh Concrete           | 109        |
| 4.7      | Result of Compaction Factor of Fresh concrete        | 113        |
| 4.8      | Result of Density of Kenaf Fibre Reinforced Concrete | 115        |
| 4.9      | Result of Water Absorption of KFRC                   | 119        |
| 4.9.1    | Result of Ultrasonic Pulse Velocity (UPV) of KFRC    | 121        |
| 4.10     | Strength and Elastic Properties of Hardened KFRC     | 126        |
| 4.10.1   | Compressive Strength of KFRC                         | 126        |

|      |          |                                                                     |     |
|------|----------|---------------------------------------------------------------------|-----|
|      | 4.10.2   | Tensile Strength of KFRC                                            | 132 |
|      | 4.10.3   | Tensile Strength of KFRC with Notched Cylindrical Sample            | 138 |
|      | 4.10.4   | Flexural Strength of KFRC                                           | 144 |
|      | 4.10.5   | Elastic Modulus for KFRC                                            | 150 |
|      | 4.10.6   | Poisson's Ratio of KFRC                                             | 156 |
| 4.11 |          | Dynamic Properties of KFRC                                          | 159 |
|      | 4.11.1   | Impact Resistance under Flexural Loading                            | 159 |
|      | 4.11.1.1 | Number of Dropping Ball for Flexural Impact Resistance              | 159 |
|      | 4.11.1.2 | Deflection to Number of Dropping Ball of Flexural Impact Resistance | 163 |
|      | 4.11.1.3 | Impact Energy of KFRC Materials Using Drop Weight Flexural Test     | 165 |
|      | 4.11.2   | Impact Resistance under Tensile Loading                             | 170 |
|      | 4.11.2.1 | Number of Dropping Ball for Tensile Impact Resistance               | 170 |
|      | 4.11.2.2 | Strain and Number of Dropping Ball Relationship                     | 174 |
|      | 4.11.2.3 | Impact Energy of KFRC Materials Using Drop Weight Tensile Test      | 175 |
| 4.12 |          | Beam Testing                                                        | 181 |
|      | 4.12.1   | Flexural Performance of KFRC Beams                                  | 181 |
|      | 4.12.2   | Load-Deflection Behaviour of KFRC at Flexural Test of Beam          | 183 |
|      | 4.12.3   | Mode of Failure of KFRC Beam under Flexural Loads                   | 185 |
|      | 4.12.4   | Strain of Steel Bars at Flexural Test of KFRC Beams                 | 188 |
|      | 4.12.5   | Strain of Concrete at Flexural Test of KFRC Beams                   | 189 |
|      | 4.12.6   | Repeated Load Test of KFRC Beams                                    | 191 |
|      | 4.12.6.1 | Hysteresis Loop                                                     | 191 |
|      | 4.12.6.2 | Load-Deflection Relationship at Repeated Load Test                  | 196 |

|          |                                                                                           |            |
|----------|-------------------------------------------------------------------------------------------|------------|
| <b>5</b> | <b>THEORETICAL ANALYSIS AND DISCUSSION</b>                                                | <b>199</b> |
| 5.1      | Introduction                                                                              | 199        |
| 5.2      | Elastic Modulus of KFRC                                                                   | 199        |
| 5.3      | Impact Energy at Flexural Impact Drop Weight Test                                         | 202        |
| 5.4      | Impact Energy of KFRC Materials Based on Tensile Load                                     | 206        |
| 5.5      | Load-Deflection Behavior of KFRC at Flexural Test of Beam                                 | 210        |
| 5.6      | Load-Deflection Behavior of KFRC under Repeated Load                                      | 214        |
| 5.7      | Effects of Kenaf Fibre on Toughness of Kenaf Fibre Reinforced Concrete Beam               | 218        |
| <b>6</b> | <b>CONCLUSION AND RECOMMENDATION</b>                                                      | <b>222</b> |
| 6.1      | Introduction                                                                              | 222        |
| 6.2      | Characterization of Kenaf Fibre                                                           | 222        |
| 6.3      | Mechanical and Dynamic Performance of KFRC Materials                                      | 223        |
| 6.4      | Mechanic and Dynamic Performance of KFRC Beams                                            | 223        |
| 6.5      | The Theoretical Investigation of Static and Dynamic Properties of KFRC Materials and Beam | 224        |
| 6.6      | Contribution of This Research Work                                                        | 224        |
| 6.7      | Recommendation                                                                            | 225        |
|          | <b>REFERENCES</b>                                                                         | <b>226</b> |
|          | Appendices A – E                                                                          | 239 – 259  |

## LIST OF TABLES

| <b>TABLE NO.</b> | <b>TITLE</b>                                                                                                              | <b>PAGE</b> |
|------------------|---------------------------------------------------------------------------------------------------------------------------|-------------|
| 2.1              | List of some natural fibres                                                                                               | 14          |
| 2.2              | Different types of fibres cost and density in market                                                                      | 14          |
| 2.3              | Natural fibres' chemical composition                                                                                      | 15          |
| 2.4              | Advantages and disadvantages of natural fibre                                                                             | 16          |
| 2.5              | Kenaf fibre mechanical properties                                                                                         | 18          |
| 2.6              | The mechanical properties of several types of fibres                                                                      | 22          |
| 2.7              | Factors affecting properties of unprocessed natural fibre reinforced concretes                                            | 23          |
| 2.8              | Effect of fibre length and volume fraction on strength parameters of jute fibre reinforced cement mortar                  | 24          |
| 2.9              | Comparison of the properties of asbestos fibre reinforced roofing sheets with those reinforced with elephant-grass fibres | 25          |
| 2.10             | Physical and chemical properties of treated and untreated agave fibre                                                     | 27          |
| 2.11             | KFRC mixture proportion                                                                                                   | 31          |
| 2.12             | 28 day splitting tension strength of KFRC cylinders                                                                       | 35          |
| 3.1              | General chemical composition of ordinary portland cement                                                                  | 52          |
| 3.2              | Typical properties of RHEOBUILD 1100                                                                                      | 56          |
| 3.3              | Characteristic of steel bars                                                                                              | 57          |
| 3.4              | Notation of fibre series for testing                                                                                      | 62          |
| 3.5              | Normal concrete mix design                                                                                                | 66          |
| 3.6              | Mixture of specimens for different fibre length                                                                           | 67          |
| 3.7              | Mixture of specimens for different fibre volume fraction                                                                  | 67          |
| 3.8              | Specimens notification for testing on optimum length of kenaf                                                             | 70          |
| 3.9              | Specimens notification for testing on optimum quantity of kenaf                                                           | 71          |
| 3.10             | The beams notation                                                                                                        | 97          |
| 4.1              | The average of tensile strength kenaf fibre bundle                                                                        | 102         |
| 4.2              | Kenaf fibre water absorption in 24 hours                                                                                  | 103         |
| 4.3              | Kenaf fibre weight before and after treatment                                                                             | 104         |

|      |                                                                                                 |     |
|------|-------------------------------------------------------------------------------------------------|-----|
| 4.4  | Slump of fresh concrete with different kenaf fibre lengths                                      | 105 |
| 4.5  | The slump of fresh concrete with different kenaf fibre volume ratios                            | 107 |
| 4.6  | Vebe time of fresh concrete with different kenaf fibre lengths                                  | 110 |
| 4.7  | Vebe time of fresh concrete with different kenaf fibre percentages                              | 111 |
| 4.8  | Compaction factor of fresh concrete with different kenaf fibre lengths                          | 113 |
| 4.9  | Compaction factor of fresh concrete with different kenaf fibre percentages                      | 114 |
| 4.10 | Density of concrete cylinders with different length of kenaf fibres                             | 116 |
| 4.11 | Density of concrete with different ratio                                                        | 118 |
| 4.12 | Average water absorption of kenaf fibre with different length in concrete cubes                 | 120 |
| 4.13 | Average water absorption of kenaf fibre with different ratio in concrete cubes                  | 121 |
| 4.14 | Ultrasonic pulse velocity (UPV) test of kenaf fibre with different length                       | 123 |
| 4.15 | Ultrasonic pulse velocity (UPV) test of kenaf fibre with different volume fraction              | 125 |
| 4.16 | Compressive strength of kenaf fibre with different fibre length                                 | 127 |
| 4.17 | Compressive strength of kenaf fibre with different fibre volume fractions in concrete cylinders | 130 |
| 4.18 | Tensile strength of KFRC with different fibre length                                            | 133 |
| 4.19 | Tensile Strength of KFRC with different fibre volume fraction                                   | 136 |
| 4.20 | Tensile strength of KFRC with different fibre length using the notched cylinder samples         | 139 |
| 4.21 | Tensile strength of KFRC with different volume fraction using the notched cylinder samples      | 142 |
| 4.22 | Flexural strength of the KFRC with different fibre length                                       | 145 |
| 4.23 | Flexural strength of the KFRC with different fibre volume fraction                              | 148 |
| 4.24 | Elastic modulus of KFRC with different fibre length                                             | 151 |
| 4.25 | Elastic modulus of KFRC with different fibre volume fraction                                    | 154 |
| 4.26 | Poisson's ratio of KFRC with different fibre length                                             | 157 |
| 4.27 | Poisson's ratio of KFRC with different fibre volume ratios                                      | 158 |

|      |                                                                                                                      |     |
|------|----------------------------------------------------------------------------------------------------------------------|-----|
| 4.28 | Average number of dropping ball for flexural drop weight test with different fibre length                            | 160 |
| 4.29 | Average number of dropping ball for flexural drop weight test with different fibre volume fraction                   | 162 |
| 4.30 | Impact energy for first crack from KFRC with different fibre length in flexural drop weight test                     | 166 |
| 4.31 | Impact energy for first crack from KFRC with different fibre volume fraction in flexural drop weight test            | 166 |
| 4.32 | Impact energy for failure mode from KFRC with different fibre length in flexural drop weight test                    | 167 |
| 4.33 | Impact energy for failure mode from KFRC with different fibre volume fraction in flexural drop weight test           | 167 |
| 4.34 | Average number of dropping ball for tensile drop weight test for different fibre length                              | 170 |
| 4.35 | Average number of dropping ball for tensile drop weight test for different fibre volume fraction                     | 172 |
| 4.36 | Impact energy of first crack for different fibre length in tensile drop weight test                                  | 176 |
| 4.37 | Impact energy of first crack for different fibre volume fraction in tensile drop weight test                         | 176 |
| 4.38 | Impact energy of failure mode for different fibre length in tensile drop weight test                                 | 177 |
| 4.39 | Impact energy of failure mode for different fibre volume fraction in tensile drop weight test                        | 177 |
| 4.40 | Ultimate load of KFRC beams at flexural test                                                                         | 182 |
| 4.41 | KFRC beam deflection in different load under flexural test                                                           | 184 |
| 4.42 | First crack load of KFRC beams at flexural test                                                                      | 186 |
| 4.43 | Number of cracks for each beam at ultimate flexural load                                                             | 186 |
| 4.44 | Maximum crack width of KFRC beams in failure load of flexural test                                                   | 188 |
| 4.45 | Average strain in steel bar from flexural test of KFRC beams                                                         | 189 |
| 4.46 | Repeated failure load                                                                                                | 191 |
| 4.47 | Beam deflection at repeated load test                                                                                | 196 |
| 5.1  | Relationship between elastic modulus and fibre length and fibre volume fraction                                      | 202 |
| 5.2  | First crack impact energy to fibre length and volume fraction relationship on flexural load with regression analysis | 204 |
| 5.3  | First crack impact energy to fibre length and volume fraction relationship on flexural load                          | 204 |

|      |                                                                                                                     |     |
|------|---------------------------------------------------------------------------------------------------------------------|-----|
| 5.4  | Failure impact energy to fibre length and volume fraction relationship on flexural load with regression analysis    | 205 |
| 5.5  | Failure impact energy to fibre length and volume fraction relationship on flexural load                             | 205 |
| 5.6  | First crack impact energy to fibre length and volume fraction relationship on tensile load                          | 208 |
| 5.7  | First crack impact energy to fibre length and volume fraction relationship on tensile load with regression analysis | 208 |
| 5.8  | Failure impact energy to fibre length and volume fraction relationship on tensile load                              | 209 |
| 5.9  | Failure impact energy to fibre length and volume fraction relationship on tensile load with regression analysis     | 210 |
| 5.10 | Load - deflection relationship of mid span for normal concrete beam at flexural test                                | 212 |
| 5.11 | Load - deflection relationship of mid span for KFRC 100 % beam at flexural test                                     | 212 |
| 5.12 | Load - deflection relationship of mid span for KFRC 50 % beam at flexural test                                      | 213 |
| 5.13 | Load - deflection relationship of mid span for normal concrete beam at repeated load test                           | 215 |
| 5.14 | Load - deflection relationship of mid span for KFRC 100 % beam at repeated load test                                | 216 |
| 5.15 | Load - deflection relationship of mid span for KFRC 50 % beam at repeated load test                                 | 216 |
| 5.16 | The areas covered under the load-deflection curved at static flexural test                                          | 218 |
| 5.17 | The areas covered under the load-deflection curved at dynamic repeated load test                                    | 220 |
| A.1  | Free Water / Cement Ratio                                                                                           | 242 |
| A.2  | Approximate Free-Water Content                                                                                      | 243 |

## LIST OF FIGURES

| <b>FIGURE NO.</b> | <b>TITLE</b>                                                                                     | <b>PAGE</b> |
|-------------------|--------------------------------------------------------------------------------------------------|-------------|
| 2.1               | Classification of fibres                                                                         | 10          |
| 2.2               | Natural fibre classification                                                                     | 12          |
| 2.3               | Structure of natural fibre                                                                       | 13          |
| 2.4               | Chemical structure of cellulose                                                                  | 13          |
| 2.5               | Lignin structure                                                                                 | 13          |
| 2.6               | Tensile strength and elastic modulus of kenaf fibres for conditions A and B                      | 18          |
| 2.7               | Relationship between tensile properties of kenaf fibres and distance for condition B             | 19          |
| 2.8               | (a) Kenaf plant. (b) the cross section of kenaf plant stem (c) kenaf fibre                       | 20          |
| 2.9               | Tensile strength of alkaline treated of kenaf fibres                                             | 28          |
| 2.10              | Effect of fibre content on compressive strength of KFRC at 28 days                               | 32          |
| 2.11              | Effect of water/cement ratio on 28 day strength of normal concrete (adapted from ACI 211.1 )     | 33          |
| 2.12              | Stress–strain relation for KFRC and normal concrete cylinders at 28 days                         | 34          |
| 2.13              | Midspan load–deflection behavior of (a) control and (b) 1.2% KFRC prisms at 28 days              | 35          |
| 2.14              | Notched specimen: 18 mm triangular notch                                                         | 37          |
| 2.15              | Possible failure mode of circular specimen: (a) without notch, (b) with notch under impact tests | 38          |
| 2.16              | Drop-weight impact test setup                                                                    | 39          |
| 2.17              | First crack impact resistance of SFRC                                                            | 41          |
| 2.18              | Failure impact resistance of SFRC                                                                | 42          |
| 2.19              | First crack impact energy of SFRC                                                                | 42          |
| 2.20              | Failure impact energy of SFRC                                                                    | 43          |
| 3.1               | Stages 1: fibre characterization                                                                 | 47          |
| 3.2               | Stages 2: kenaf fibre reinforced concrete characteristics                                        | 48          |



|      |                                                                                                                                                        |    |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 3.3  | Stage3: structural behaviour of KFRC beams                                                                                                             | 49 |
| 3.4  | Kenaf fibre: (a) seed, (b) plant, (c) bast, (d) extracting, (e) kenaf bundle                                                                           | 51 |
| 3.5  | Ordinary portland cement                                                                                                                               | 52 |
| 3.6  | (a) Coarse aggregates (b) fine aggregates                                                                                                              | 53 |
| 3.7  | Distilled water machine                                                                                                                                | 54 |
| 3.8  | Sodium hydroxide (NaOH)                                                                                                                                | 55 |
| 3.9  | (a) Steel bar 10, 12 mm, (b) steel bar 6 mm                                                                                                            | 57 |
| 3.10 | Pretreatment process                                                                                                                                   | 59 |
| 3.11 | Untreated kenaf fibre                                                                                                                                  | 60 |
| 3.12 | Treatment process: (a) pretreatment, (b) immersed in NaOH, (c) immersed in distilled water, (d) washing with distilled water, (e) drying               | 61 |
| 3.13 | Tensile testing machine                                                                                                                                | 62 |
| 3.14 | Single fibre tensile test specimen                                                                                                                     | 63 |
| 3.15 | Kenaf fibre sample for water absorption                                                                                                                | 64 |
| 3.16 | Kenaf for concrete mix                                                                                                                                 | 65 |
| 3.17 | (a) Cubes (50mm ×50mm ×50mm), (b) cylinder (100mm ×200mm), (c) cylinder (100mm × 100mm) with 18 mm triangular notch, (d) prisms (100mm × 100mm ×500mm) | 68 |
| 3.18 | Slump test                                                                                                                                             | 73 |
| 3.19 | Vebe time machine                                                                                                                                      | 73 |
| 3.20 | Compaction factor test machine                                                                                                                         | 75 |
| 3.21 | Pulse velocity measurement configurations. (A) direct method. (B) semi direct method. (C) indirect surface method.                                     | 77 |
| 3.22 | Compressive test of concrete cylinders                                                                                                                 | 78 |
| 3.23 | Tensile strength test                                                                                                                                  | 79 |
| 3.24 | Quasi-static tensile test machine                                                                                                                      | 80 |
| 3.25 | Flexural machine test for prism                                                                                                                        | 80 |
| 3.26 | Procedure of capping                                                                                                                                   | 81 |
| 3.27 | Test setup on elastic modulus and poisson's ratio                                                                                                      | 83 |
| 3.28 | Layout of the instrumented drop weight impact system                                                                                                   | 84 |
| 3.29 | Drop weight tensile cylinders                                                                                                                          | 85 |
| 3.30 | Test setup for drop weight flexural prism                                                                                                              | 86 |
| 3.31 | Strain gauge structure                                                                                                                                 | 88 |
| 3.32 | Demec machine and instruments                                                                                                                          | 89 |
| 3.33 | The linear voltage displacement transducer (LVDT)                                                                                                      | 90 |
| 3.34 | Hydraulic jack                                                                                                                                         | 90 |
| 3.35 | Load cell                                                                                                                                              | 91 |

|      |                                                                                    |     |
|------|------------------------------------------------------------------------------------|-----|
| 3.36 | Data logger TDS-530                                                                | 92  |
| 3.37 | Geometry of beam specimen                                                          | 92  |
| 3.38 | Bar bend machine used to bend steel bars into desire shape                         | 93  |
| 3.39 | Steel reinforcements with link bars                                                | 94  |
| 3.40 | Strain gauge on the concrete                                                       | 95  |
| 3.41 | Strain gauge for steel                                                             | 96  |
| 3.42 | Beam sample size (150mm ×200mm×2200mm)                                             | 96  |
| 3.43 | Curing the RC beams                                                                | 97  |
| 3.44 | Schematic loading system of the RC beams                                           | 98  |
| 4.1  | The average tensile strength of kenaf fibre bundle                                 | 102 |
| 4.2  | Effect of pretreatment and treatment to weight of kenaf fibre                      | 104 |
| 4.3  | Slump of fresh concrete with different kenaf fibre lengths                         | 105 |
| 4.4  | Average slump of fresh concrete with different kenaf fibre lengths                 | 106 |
| 4.5  | Samples of fresh concrete after slump test with different kenaf fibre lengths      | 106 |
| 4.6  | The slump of fresh concrete with different kenaf fibre percentage                  | 108 |
| 4.7  | The average slump of fresh concrete with different kenaf fibre percentage          | 108 |
| 4.8  | Samples of fresh concrete after slump test with different fibre volume ratios      | 109 |
| 4.9  | Vebe time of fresh concrete with different kenaf fibre lengths                     | 110 |
| 4.10 | Average vebe time of fresh concrete with different kenaf fibre lengths             | 111 |
| 4.11 | Vebe time of fresh concrete with different kenaf fibre percentages                 | 112 |
| 4.12 | Average vebe time of fresh concrete with different kenaf fibre percentages         | 112 |
| 4.13 | Compaction factor of fresh concrete with different kenaf fibre lengths             | 113 |
| 4.14 | Average compaction factor of fresh concrete with different kenaf fibre lengths     | 114 |
| 4.15 | Compaction factor of fresh concrete with different kenaf fibre percentages         | 115 |
| 4.16 | Average compaction factor of fresh concrete with different kenaf fibre percentages | 115 |
| 4.17 | Density of concrete cylinders with different length of kenaf fibres                | 117 |

|      |                                                                                                   |     |
|------|---------------------------------------------------------------------------------------------------|-----|
| 4.18 | Average density of concrete with different length of fibre                                        | 117 |
| 4.19 | Density of concrete with different ratio of kenaf                                                 | 119 |
| 4.20 | Average density of concrete with different ratio of fibre                                         | 119 |
| 4.21 | Average water absorption of KFRC with different length                                            | 120 |
| 4.22 | Average water absorption of KFRC with different ratio                                             | 121 |
| 4.23 | Ultrasonic pulse velocity (UPV) test of KFRC with different fibre length                          | 124 |
| 4.24 | Average ultrasonic pulse velocity (UPV) test of KFRC with different fibre length                  | 124 |
| 4.25 | Ultrasonic pulse velocity (UPV) test of KFRC with different fibre volume fraction                 | 126 |
| 4.26 | Average ultrasonic pulse velocity (UPV) test of KFRC with different fibre volume fraction         | 126 |
| 4.27 | Compressive strength of KFRC with different fibre length                                          | 128 |
| 4.28 | Average compressive strength of KFRC with different length                                        | 129 |
| 4.29 | Mode of failure of KFRC cylinders with different fibre length                                     | 129 |
| 4.30 | Compressive strength of KFRC with different fibre volume fractions                                | 131 |
| 4.31 | Average compressive strength of KFRC with different fibre volume fraction                         | 132 |
| 4.32 | Mode of failure cylinders with different fibre volume fractions after compressive test            | 132 |
| 4.33 | Tensile strength of KFRC with different fibre length                                              | 134 |
| 4.34 | Average tensile strength of KFRC with different fibre length                                      | 135 |
| 4.35 | Mode of failure of KFRC cylinder in tensile test with different fibre length                      | 135 |
| 4.36 | Tensile strength of KFRC with different fibre volume fraction                                     | 137 |
| 4.37 | Average tensile strength of KFRC with different fibre volume fraction                             | 138 |
| 4.38 | Mode of failure of KFRC Cylinder in tensile test with different fibre volume fraction             | 138 |
| 4.39 | Tensile strength of KFRC with different fibre length using the notched cylinder samples           | 140 |
| 4.40 | Average tensile strength of KFRC with different fibre length using the notched cylinder samples   | 140 |
| 4.41 | Mode of failure of KFRC notched cylinder after tensile test with different fibre length           | 141 |
| 4.42 | Tensile strength of KFRC with different volume fraction length using the notched cylinder samples | 143 |

|      |                                                                                                                                                                                           |     |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 4.43 | Average tensile strength of KFRC with different fibre volume fraction using the notched cylinder samples                                                                                  | 143 |
| 4.44 | Mode of failure of KFRC notched cylinder after tensile test with different fibre volume fraction                                                                                          | 144 |
| 4.45 | Flexural strength of the KFRC with different fibre length                                                                                                                                 | 146 |
| 4.46 | The average flexural strength of KFRC with different fibre length                                                                                                                         | 146 |
| 4.47 | Mode of failure of KFRC samples with different fibre length                                                                                                                               | 147 |
| 4.48 | Flexural strength of the KFRC with different fibre volume fraction                                                                                                                        | 149 |
| 4.49 | The average flexural strength of KFRC with different fibre volume fraction                                                                                                                | 149 |
| 4.50 | Mode of failure of KFRC samples with different fibre volume fraction                                                                                                                      | 150 |
| 4.51 | Stress-strain of KFRC and normal concrete for elastic modulus under compressive load with different fibre length: (a): normal, (b): 10 mm, (c): 15 mm, (d): 20 mm, (e): 25 mm, (f): 30 mm | 152 |
| 4.52 | Average elastic modulus of KFRC with different fibre length                                                                                                                               | 153 |
| 4.53 | Mode of failure after elastic modulus test on KFRC with different fibre length                                                                                                            | 153 |
| 4.54 | Stress-strain of KFRC and normal concrete for elastic modulus under compressive load: (a): normal, (b): 0.5 %, (c): 1 %, (d): 1.5 %, (e): 2 %                                             | 155 |
| 4.55 | Average elastic modulus of KFRC with different fibre volume fraction                                                                                                                      | 156 |
| 4.56 | Mode of failure after elastic modulus test on KFRC with different fibre volume fraction                                                                                                   | 156 |
| 4.57 | Average poisson's ratio of KFRC with different fibre length                                                                                                                               | 157 |
| 4.58 | Average poisson's ratio for different volume ratios of KFRC                                                                                                                               | 158 |
| 4.59 | Average number of dropping ball in flexural test with 0.5 m height for different fibre length                                                                                             | 160 |
| 4.60 | Average number of dropping ball in flexural test with 1 m height for different fibre length                                                                                               | 161 |
| 4.61 | Average number of dropping ball in flexural test with 0.5 m height for different fibre volume fraction                                                                                    | 162 |
| 4.62 | Average number of dropping ball in flexural test with 1 m height for different fibre volume fraction                                                                                      | 163 |

|      |                                                                                                                          |     |
|------|--------------------------------------------------------------------------------------------------------------------------|-----|
| 4.63 | Average deflection to number of dropping ball for different fibre length in flexural drop weight test                    | 164 |
| 4.64 | Average deflection to number of dropping ball for different fibre volume fraction in flexural drop weight test           | 165 |
| 4.65 | Impact energy of first crack for different fibre length in flexural drop weight test                                     | 166 |
| 4.66 | Impact energy of first crack for different fibre volume fraction in flexural drop weight test                            | 167 |
| 4.67 | Impact energy of failure mode for different fibre length in flexural drop weight test                                    | 168 |
| 4.68 | Impact energy of failure mode for different fibre volume fraction in flexural drop weight test                           | 168 |
| 4.69 | Average impact energy for different fibre length in flexural drop weight test                                            | 169 |
| 4.70 | Average impact energy for different fibre volume fraction in flexural drop weight test                                   | 169 |
| 4.71 | Average number of dropping ball in tensile drop weight test with 0.5 m height for different fibre length                 | 171 |
| 4.72 | Average number of dropping ball in tensile drop weight test with 1 m height for different fibre length                   | 171 |
| 4.73 | Average number of dropping ball in tensile drop weight test with 0.5 m height for different fibre volume fraction        | 173 |
| 4.74 | Average number of dropping ball in tensile drop weight test with 0.5 m height for different fibre volume fraction        | 173 |
| 4.75 | Average strain and number of dropping ball relationship in tensile drop weight test with different fibre length          | 174 |
| 4.76 | Average strain and number of dropping ball relationship in tensile drop weight test with different fibre volume fraction | 175 |
| 4.77 | Impact energy of first crack for different fibre length in tensile drop weight test                                      | 176 |
| 4.78 | Impact energy of first crack for different fibre volume fraction in tensile drop weight test                             | 177 |
| 4.79 | Impact energy of failure mode for different fibre length in tensile drop weight test                                     | 178 |
| 4.80 | Impact energy of failure mode for different fibre volume fraction in tensile drop weight test                            | 178 |
| 4.81 | Average impact energy for different fibre length in tensile drop weight test                                             | 179 |

|       |                                                                                         |     |
|-------|-----------------------------------------------------------------------------------------|-----|
| 4.82  | Average impact energy for different fibre volume fraction in tensile drop weight test   | 179 |
| 4.83  | Mode of failure in tensile drop weight test for different fibre length                  | 180 |
| 4.84  | Mode of failure in tensile drop weight test for different fibre volume fraction         | 181 |
| 4.85  | Mode of failure normal concrete beam under flexural test                                | 182 |
| 4.86  | Mode of failure KFRC 50 % concrete beam under flexural test                             | 183 |
| 4.87  | Mode of failure KFRC 100 % concrete beam under flexural test                            | 183 |
| 4.88  | Load - deflection relationship of mid span KFRC beams at flexural testing               | 184 |
| 4.89  | Load - deflection relationship of load position KFRC beams at flexural testing          | 185 |
| 4.90  | The crack pattern of beams in flexural test, (a): normal, (b): 100% KFRC, (c): 50% KFRC | 187 |
| 4.91  | Crack width at various level of loads during flexural test for KFRC beams               | 188 |
| 4.92  | Average strain in steel bar from flexural test                                          | 189 |
| 4.93  | Strain in compression section beams at flexural test                                    | 190 |
| 4.94  | Strain in tension section beam at flexural test                                         | 190 |
| 4.95  | Hysteresis loop of normal beam                                                          | 193 |
| 4.96  | Hysteresis loop for 50 % KFRC beam                                                      | 194 |
| 4.97  | Hysteresis loop for 100 % KFRC beam                                                     | 195 |
| 4.98  | Load-deflection relationship at repeated load test on normal concrete beam              | 197 |
| 4.99  | Load-deflection relationship at repeated load test on 50% KFRC concrete beam            | 197 |
| 4.100 | Load-deflection relationship at repeated load test on 100% KFRC concrete beam           | 198 |
| 5.1   | Log E vs log KFRC with different fibre length                                           | 200 |
| 5.2   | Log E vs log KFRC with different fibre volume fraction                                  | 201 |
| 5.3   | Relationship between elastic modulus and fibre length                                   | 201 |
| 5.4   | Relationship between elastic modulus and fibre volume fraction                          | 202 |
| 5.5   | First crack impact energy to fibre length relationship on flexural load                 | 204 |

|      |                                                                                                    |     |
|------|----------------------------------------------------------------------------------------------------|-----|
| 5.6  | First crack impact energy to fibre volume fraction relationship on flexural load                   | 205 |
| 5.7  | Failure impact energy to fibre length relationship on flexural load                                | 206 |
| 5.8  | Failure impact energy to fibre volume fraction relationship on flexural load                       | 206 |
| 5.9  | First crack impact energy to fibre length relationship on tensile load                             | 207 |
| 5.10 | First crack impact energy to fibre volume fraction relationship on tensile load                    | 208 |
| 5.11 | Failure impact energy to fibre length relationship on tensile load                                 | 209 |
| 5.12 | Failure impact energy to fibre volume fraction relationship on tensile load                        | 209 |
| 5.13 | Load deflection relationship for normal concrete beam at flexural test                             | 213 |
| 5.14 | Load deflection relationship for KFRC 100 % concrete beam at flexural test                         | 214 |
| 5.15 | Load deflection relationship for KFRC 50 % concrete beam at flexural test                          | 214 |
| 5.16 | Load deflection relationship for normal concrete beam at repeated loading                          | 217 |
| 5.17 | Load deflection relationship for KFRC 100 % concrete beam at repeated loading                      | 217 |
| 5.18 | Load deflection relationship for KFRC 50 % concrete beam at repeated loading                       | 217 |
| 5.19 | Area covered under the load deflection curved of normal concrete at flexural test (area=toughness) | 219 |
| 5.20 | Area covered under the load deflection curved of 100% KFRC at flexural test                        | 219 |
| 5.21 | Area covered under the load deflection curved of 50% KFRC at flexural test                         | 219 |
| 5.22 | Area covered under the load deflection curved of normal concrete at repeated load test             | 221 |
| 5.23 | Area covered under the load deflection curved of 100% KFRC at repeated load test                   | 221 |
| 5.24 | Area covered under the load deflection curved of 50% KFRC at repeated load test                    | 221 |

|     |                                                                         |     |
|-----|-------------------------------------------------------------------------|-----|
| A.1 | Relationship between Standard Deviation, S, and Characteristic Strength | 240 |
| A.2 | K : from characteristic strength                                        | 240 |
| A.3 | Relation Between Compressive Strength And Free Water / Cement Ratio     | 242 |
| A.4 | Estimated Wet Density Of Fully Compacted Concrete                       | 244 |
| A.5 | Proportion of Fine Aggregate                                            | 245 |
| A.6 | Concrete mix design                                                     | 246 |
| B.1 | Stress and strain plain for normal concrete beam design                 | 250 |
| E.1 | Stress and strain plain for KFRC concrete beam design                   | 262 |
| E.2 | The moment and shear diagram for beam                                   | 263 |



## LIST OF ABBREVIATIONS

|       |   |                                                           |
|-------|---|-----------------------------------------------------------|
| EFB   | – | Empty Fruit Bunch                                         |
| MARDI | – | Malaysian Agricultural Research and Development Institute |
| LTN   | – | Tobacco Board of Malaysia                                 |
| BS    | – | British Standard                                          |
| ASTM  | – | American Society for Testing and Materials                |
| DRY   | – | Dry Sample                                                |
| GGBS  | – | Ground Granulated Blast Furnace Slag                      |
| PFA   | – | Pulverized Fuel Ash                                       |
| KFRC  | – | Kenaf Fibre Reinforced Concrete                           |
| FRP   | – | Fibre Reinforced polymer                                  |
| NaOH  | – | Sodium Hydroxide                                          |
| PVA   | – | Polyvinyl Alcohol                                         |
| NFRC  | – | Natural Fibre Reinforced Concrete                         |
| RC    | – | Reinforced Concrete                                       |
| ACI   | – | American Concrete Institute                               |
| UNF   | – | Unprocessed Natural Fibre                                 |
| PNF   | – | Processed Natural Fibre                                   |
| PNFRC | – | Processed Natural Fibre Reinforced Concrete               |

## LIST OF SYMBOLS

|                  |   |                                                         |
|------------------|---|---------------------------------------------------------|
| $b$              | - | Beam Width                                              |
| $h$              | - | Beam Height                                             |
| $A$              | - | Section Area                                            |
| $L$              | - | Length of Beam                                          |
| $d$              | - | Height to Tension Steel Bar                             |
| $d'$             | - | Height to Compression Steel Bar                         |
| $f_c$            | - | Concrete Cylinder Compressive Strength                  |
| $f_y$            | - | Yield Strength of Steel Flexural Reinforcement          |
| $f(\text{cube})$ | - | Concrete Cube Compressive Strength                      |
| $F_c$            | - | Concrete Force                                          |
| $F_s$            | - | Compression Steel Force                                 |
| $F_{sd}$         | - | Tension Steel Force                                     |
| $C_c$            | - | Concrete Compression Force                              |
| $C_s$            | - | Steel Compression Force                                 |
| $T$              | - | Steel Tension Force                                     |
| $X$              | - | Natural Axis                                            |
| $E_s$            | - | Steel Modulus of Elasticity                             |
| $E_c$            | - | Concrete Modulus of Elasticity                          |
| $E(\text{KFRC})$ | - | Kenaf Reinforced Concrete Modulus of Elasticity         |
| $C$              | - | Compression Depth                                       |
| $Z$              | - | Tension Depth                                           |
| $a_v$            | - | Distance between Load and Beam Edge                     |
| $M$              | - | Moment                                                  |
| $M_r$            | - | Moment Resistance                                       |
| $M_u$            | - | Measured Ultimate Moment of Tested Beam                 |
| $y$              | - | Location Measured From the Neutral Axis ( $0 < y < c$ ) |
| $g$              | - | Acceleration of Gravity                                 |
| $A_s$            | - | Compression Steel Area                                  |
| $A_s'$           | - | Tension Steel Area                                      |

**LIST OF APPENDICES**

| <b>APPENDIX</b> | <b>TITLE</b>                              | <b>PAGE</b> |
|-----------------|-------------------------------------------|-------------|
| A               | Design of Mix                             | 239         |
| B               | Theoretical Analys Normal Concrete Design | 247         |
| C               | Theoretical Analys Plain Concrete         | 251         |
| D               | Theoretical Analys 50% KFRC Concrete      | 255         |
| E               | Theoretical Analys 100% KFRC Concrete     | 259         |

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Natural fibres' first application dates back to 3000 years ago in Egypt. They were used in composite systems by mixing straw and clay in order to build walls. Natural fibres have increasingly been used for industrial applications such as sport equipment, automotive application and construction material for structural and non-structural elements [1–4]. Natural fibres were utilized as a part of early human development in fabric applications. A well-known natural fibre in Malaysia is kenaf fibre which has been used in bio composite in the local construction industry. Kenaf fibres have got specific features such as stiffness, impact resistance, flexibility, and modules. They are easily accessible [5–9], and are also renewable. Furthermore, kenaf fibre has other special features such as low cost, low density, less skin and respiratory irritation, less equipment abrasion, increased energy absorption, and vibration damping [5–8, 10, 11] which have caused them to be considered as an appropriate substitute for traditional materials such as rope, mats, straw. Kenaf fibres are considered hydrophilic materials [12–14]. Hydrophilic materials are known for absorption of water or moisture. Because of such property, fibre-matrix interface adhesion is improved due to interaction between cellulosic and water. In fact, the age and species of the plant can change cellulose quantity. Cellulose is a semi crystalline polysaccharide hydrophilic component composing of a linear chain of anhydroglucose units, which encompass alcoholic hydroxyl groups. Summarily, kenaf fibre is a kind of green material.

Conventional concretes are mainly composed of cement, water and aggregates. When used in large quantity, the environmental issue arising which contributes to global warming cannot be disregarded. Until recent decade, there has been an expanding interest on fibre reinforced concrete. The potentiality of natural fibres replacing synthetic fibres in composites is conceivable [15]. It is generally believed that some measures should be taken to sustain the world. Since concrete is considered

as a brittle material, its enrichment with distributed short fibres is believed to increase the toughness of matrix and transferring the load between the concrete components from kenaf fibre. This is achieved by prohibiting the concrete from propagating of crack. However, reinforcing concrete with kenaf fibre improves its tensile properties and makes it resistant to dynamic and earthquake loading. The composite material has been slowly accepted locally as an alternative construction material due to its ability to sustain structural loads comparable to the existing conventional materials such as synthetic and steel fibres.

## **1.2 Background of the Study**

Nowadays synthetic fibre reinforced concrete (FRC) such as glass, carbon, and aramid are commonly used for strengthening of RC structures due to their mechanical properties such as high modulus of elasticity, relative low extension coefficient, and corrosive resistance. However, these materials are expensive in terms of costs and material production [9]. Besides, they are also not biodegradable materials. In recent years, awareness regarding the cost and environmental impact of synthetic materials throughout their manufacture, use and end-life has increased. Furthermore, environmental problems arise when synthetic materials are used in large quantities, which are difficult to overcome. Landfill method is not considered economical, and the open burning results in air pollution, which can lead to global warming. Unlike the synthetic fibres, natural fibres are cheaper, lighter, more environmental friendly and also are available in large quantities [16]. In general, natural fibres offer high specific properties such as having low cost being nonabrasive, renewable and environmental friendly [4]. The environmental issues examined are climate change, fossil fuel depletion, ozone depletion, eco-toxicity, waste disposal, water extraction, acid deposition, eutrophication (over enrichment of water sources), summer smog (low level ozone creation) and minerals extraction. This issue caused the increase in carbon dioxide, CO<sub>2</sub> gaseous which creates harmful environment and human health problems [17]. These advantages of natural fibres outweigh those of synthetic fibres. There is a universal movement toward the realization of a “Green World” and the need is great for participation in preserving the environment and making the world more affordable and safer to live in.

Recently, many researchers show interest in natural fibre reinforced concrete, and the potentiality of natural fibres in replacing synthetic fibres in composites is increasingly addressed. Natural fibres are combined with concrete matrix to form a

bio composite. Natural fibres are agro-based and appear in different types based on source including leaf (pineapple fibre, sisal and henequen), bast (kenaf, jute, flax, hemp and ramie), fruit (empty fruit bunch), cotton, rice husks and rice straw [18]. The vegetable fibres contain cellulose, hemicellulose, lignin and pectin. Due to this, all natural fibres have high affinity for water and moisture which is referred to as hydrophilicity [12–14]. Kenaf fibres are also classified as cellulose fibre. In Malaysia, the National Kenaf Research and Development Program has been developed to incorporate kenaf for new industrial products. The Malaysian government has spent around RM12 million for conducting research on Kenaf-based industry in line with 9th Malaysia plan (2006–2010). In the bid to expand kenaf production, Malaysian Agricultural Research and Development Institute (MARDI) initiated research on kenaf plantation according Kenaf and Tobacco Board of Malaysia (LKTN) has developed kenaf fields and production in Kelantan and Terengganu.

Many studies have shown that the dynamic resistance can be increased substantially with the addition of randomly distributed fibres in concrete. Fibre reinforced concrete mixes were found to be more sensitive compared to respective unreinforced matrices. Kenaf fibre with characteristics such as renewable, biodegradable, high energy absorption, resistance to dynamic loading and corrosion is the best type of natural fibre for improving properties of concrete. On the other hand, natural fibre reinforced concrete has good resistance to vibration dynamic effect. Addressing the above issues, this study is carried out to investigate features of kenaf fibre reinforced concrete (KFRC). This study is aimed at examining the potential of kenaf fibres as a fibre from natural source and the capacity of kenaf fibre reinforced concrete in structural application [19].

### **1.3 Statement of the Problem**

In response to solving the brittle behaviour of conventional material, fibre reinforced concrete had been emerged and such materials as steel fibres and synthetics fibres are used as structural elements in concrete structures. Although, in spite of having a good resistance of tensile force, they are easily corroded when exposed for a long period of time. Past research has been done to find another alternative for replacement of steel materials because of the expensive costs and high maintenances. In case of, synthetics fibres it is found that they exhibit high cost of production [17], and not environmentally friendly [16]. Besides, they affect on humans' health such as skin and respiration problem [10]. Thus, synthetic fibres give negative impact since

they are usually disposed by landfill or open burning methods. Landfill method is not economical because of the limited space for disposal nowadays whilst open burning results in air pollution and global warming.

Therefore, the natural fibre reinforced concrete composites is introduced as the sustainable material for structural elements to overcome the problems faced by using synthetics based fibres [20]. On the other hand, natural fibres do not have any negative impact to environment. In addition, researchers are seeking for green materials for composites, named as bio composites. Kenaf fibre known to be natural fibre are used as reinforcing fibre in concrete. This makes kenaf fibre an appropriate replacement to steel and synthetic material in conventional concrete.

One of the disadvantage of kenaf fibre is the hydrophilic surface which is not compatible with concrete, resulting in significant interfacial stress between matrix and fibre. This negative property of natural kenaf fibre can be resolved by chemical surface treatment method to enhance the properties of kenaf fibre and fibre matrix interface. Alkali treatment has shown to result in the removal of cementing materials, hemicelluloses and lignin, from the inter fibrillary regions and impurities such as oils and wax from the fibre surface leading to roughness of fibre surface, which improves the composite interface bonding via interlock between fibre and cement paste.

Reconstructing or rebuilding the reinforced concrete beam is not acceptable when it's cracked and is in an unstable position. This is due to the associated time and cost which is not economical in construction. . Thus, the inclusion of fibre in concrete is proposed in this study as an appropriate technique to resisting dynamic and static loading on concrete [21].

KFRC are recyclable materials that are designed to decompose rapidly. Therefore, KFRC offers environmental benefits, light weight concrete composite, good mechanical properties, resistance to corrosion, and good dynamic vibration behaviour. Kenaf fibre reinforced concrete is green material which has drawn the attention of the world to its potential. All the mention advantages calls for conducting research at this material to replace for the currently used fibre.

## 1.4 Objective of the Study

The aim objective of this study is to investigate the potential of kenaf fibre as reinforcement in concrete. The specific objectives of this study are as follows:

- a) To examine the kenaf fibre characteristics for fibre reinforced concrete materials.
- b) To investigate the compressive, tensile, bending, and impact properties of kenaf fibre reinforced concrete.
- c) To determine the load - deformation behaviour of kenaf fibre reinforced concrete beams under short term flexural loads and repeated loadings.
- d) To evaluate the analytical model of kenaf fibre reinforced concrete materials and structures under dynamic loadings.

## 1.5 Scope of the Study

This study involves three main phases, namely material properties, application of reinforced concrete beams behaviour and analytical process.

**Material properties:** The physical and mechanical properties of kenaf fibre which is supplied by the national kenaf and tobacco board (Malaysia) as long fibre are determined due to four different setting of chemical surface modifications by NaOH solution. According to ASTM C1557-03 (approved 2008) [22]. A number of 35 specimens are used to determine the average tensile properties of kenaf fibre. Also the water absorption test is conducted in order to determine the optimum water absorption of kenaf fibre. This optimum water content is essential to determine the additional water in mix design.

**Application of reinforced concrete beams behaviour:** This part is conducted experimentally to investigate the performance of kenaf fibre reinforced concrete to find the optimum value of length and effect volume fraction. In this study there are four different moulds of concrete cubes, prisms, cylindrical, and cylindrical with notch. The samples with different fibre length (10mm, 15mm, 20mm, 25mm, and 30mm) at 1% volume fraction of fibre are employed to investigate the optimum length of fibre. Following this test the archived optimum length is applied for different fibre volume fraction (0.5%, 1%, 1.5%, and 2%) to examine the effective percentage of



kenaf fibre. Total number of composite series and specimens are 10 and at least 500 respectively. Slump, vebe time, compaction factor, density, ultrasonic pulse velocity, compressive, flexural, tensile, quasi-static splitting tensile, elastic modulus and poisson ratio, dynamic tensile drop weight and flexural drop weight tests is the second phase test. In this phase different configurations and test methods to find the optimum values for Kenaf Fibre Reinforced Concrete (KFRC) material is applied. Hence, the behaviour of structural sample of KFRC beams including concrete beams without fibre contents and the once with optimum volume fraction and optimum fibre length are produced. The flexural and repeated load testing are carried out according to ASTM standards by using Universal Testing Machine. Total number of 18 beams are produced and tested. The aim of this test is to determine the flexural properties and dynamic behaviour of kenaf fibre reinforced concrete beam. Also the load, mid-span and load position deflection, tensile steel strain at the mid span and crack wide are reported as result of test for further discussion and analysis.

**Analytical process:** Finally, the last phase present different analytical pathways. The test results are analysed and used to propose the best guide line and procedures for KFRC material to be used in the construction industry.

## 1.6 Significant of Study

The significant findings of this research can help researchers:

1. To introduce the use of green materials for engineering applications is the main goal of this study. This can help to save the nature and to reduce the emission of carbon dioxide.
2. According to the environmental concerns of the man-made materials such as steel bar and synthetic fibre for reinforced concrete composites, natural material like kenaf fibres becomes the best replacing material for using reinforced fibre in concrete composite field because of their sustainability, lightness and other advantages.
3. Increasing the knowledge of RC properties by using of kenaf fibre, can encourage others to follow this kind of research to gain a sustainable material.
4. Furthermore, this study can define new application of natural fibre and also will benefit engineers and industries to use of renewable materials. This study

establishes design and construction procedure of kenaf fibre reinforced concrete to assist designer, engineer and architect.

5. Moreover, it may succour the agronomic activities and improve economic sector in Malaysia due to the demands of kenaf fibre production.
6. To investigate the mechanical and dynamic properties of kenaf fibre composite.
7. To evaluate the mechanical and dynamic properties of kenaf fibre reinforced concrete beam in structural properties.

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